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BASIC REQUIREMENTS OF FUEL-INJECTION NOZZLES FOR QUIESCENT COMBUSTION CHAMBERS

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Summary

This report presents test results obtained at the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics during an investigation of the performance of a single-cylinder, high-speed, compression-ignition test engine when using multiple-orifice fuel-injection valve nozzles in which the number and the direction of the orifices were varied independently. The orifice sizes generally conformed to the principle that the orifice area should be proportional to the volume of air served by the orifice.

The test results indicate that it is unnecessary to follow the proportional principle to extremes and that complication of nozzle design does not give a commensurate increase in performance. The optimum angle between orifice axes was judged to be 25° for the conditions in this quiescent combustion chamber, but this value is not critical.

Introduction

In the course of the general program for the investigation and development of the high-speed, compression-ignition, fuel-injection engine as a power plant for aircraft, the staff of the Langley Memorial Aeronautical Laboratory has been determining the performance of a single-cylinder test engine with a vertical disk-shaped combustion chamber in a cylinder head, designated in the test series N.A.C.A. cylinder head No. 4. The combustion chamber in this cylinder head is considered quiescent because there is no evidence that the movement of the air in the combustion chamber has any effect on the distribution of fuel. Various multiple-orifice injection-valve nozzles have been used for introducing the fuel into the combustion chamber, and former tests as reported in N.A.C.A. Technical Note No. 344 (Reference 1) indicated that for this type of combustion chamber the area of each orifice in a multiple-orifice nozzle should be proportional to the volume of air it served.

The forced air flow in this quiescent combustion chamber during injection of the fuel is of such a low velocity that it has a negligible effect on the distribution of the fuel and there is no evidence of residual air flow. Therefore, to obtain as nearly a homogeneous mixture of fuel and air as possible, it is necessary to meter the fuel to the air in the combustion chamber by using the proper arrangement of the discharge orifice or orifices. The assumptions necessary for a practical basis for these tests are that in carefully manufactured nozzles with round-hole orifices the coefficient of discharge will be the same for all orifices, and that the same discharge pressure will be acting on each orifice. These assumptions seem reasonable, and therefore all factors in the formula for quantities discharged become identical, except for the areas, and it follows that the amount of fuel discharged by each individual orifice will be proportional to the area of the orifice. If, then, each orifice area is in the same ratio to the total discharge area as the volume of air it serves is to the total volume of air served, the effectiveness of distribution will be dependent upon the dispersion of the fuel in the spray and the shape of the volume served.

To determine just how far it was advisable to follow this principle comparative performance tests were conducted with a series of nozzles extending this idea beyond limits practicable in the construction of nozzles for commercial engines.

To determine the optimum angle between sprays another series of comparative performance tests was run with nozzles in which the orifice areas were held constant and the angle varied.

Apparatus and Methods

The test equipment and general test methods used for the tests herein reported are the same as in Reference 1, except as specifically noted.

The combustion chamber was made as nearly quiescent as possible by using a new throat orifice (Fig. 1) that had a larger opening than used in former tests and was so shaped as to disturb the orderly forced flow of the air as little as possible and to prevent residual flow and formation of small vortices. The larger opening increased the clearance volume so that the compression ratio was 12.6:1 instead of 13.6:1, as in former tests.

Compression pressures and maximum-cylinder pressures were indicated by means of the balanced diaphragm type of maximum-cylinder-pressure indicator (Reference 2) in place of the trapped-pressure apparatus used in the former tests. Instead of recording a double reading for maximum-cylinder pressures as described in Reference 2, the operator recorded what he considered a fair average. No attempt was made to operate the engine at a particular value of maximum-cylinder pressure; instead, the pump was adjusted to give the desired fuel quantity and then the timing was advanced until a faint knock was heard.

Full-load fuel quantity 0.000325 pound per cycle is that quantity of fuel which will be completely burned, assuming perfect combustion, with the amount of air inducted per cycle at 82.5 per cent volumetric efficiency. The test results are not corrected for either barometric pressure or humidity. The injection period as observed with an oscilloscope (Reference 3) was about 35 to 37 crank degrees. The standard test speed was 1500 r.p.m.

Series E nozzles.- In the designing of nozzles for this series of performance tests it was decided to abandon the angular spacing used in the former tests and to standardize on an angle that would remain constant for all orifices. From data obtained from spray photographs by the Fuel Injection Section (Reference 4) on comparable orifices tested under conditions comparable except for temperature, it was found that the average value for spray-cone angle was 20°. Twenty degrees was therefore adopted as a standard spray-cone angle for the Series E nozzles, and all air-volume calculations were based on this value.

To continue with a design of nozzle that could be compared with those used in the former tests, the diameters of the 2 central main orifices were maintained at 0.018 inch and the volume of air in the mechanical clearance space between the piston crown and the cylinder head was divided equally between these orifices for purposes of proportioning the other orifices. A total of 16 orifices was used with 6 in one plane and 5 in each of 2 planes which were on either side of the first plane, as shown in Figure 2. The orifices were drilled 2 at a time in the order indicated by the numbering in Figure 2. The designation of these nozzles is by the use of the letter E with a number denoting the number of orifices in the nozzle at the time of test.

There is a slight deviation from the proportional-area principle in the E-series nozzles after E_{12}, because it was considered impracticable to use orifices smaller than 0.005-inch diameter. This deviation is not serious because the percentage of the total orifice area involved is smaller than the experimental error.

The performance test results shown in Figures 3 and 4 indicate that no justifiable gain would be obtained by using more than 6 orifices for this cylinder head. This conclusion simplifies further work with this cylinder head.

Series F nozzles.- There were a number of indications during these tests that the 20° angle between sprays was not the optimum, and the decision to continue with the 6-orifice nozzles made it comparatively easy to investigate the effect on engine performance of varying the angle between the axes of the individual sprays.

About this time the results of the work on dispersion at the Pennsylvania State College were published (Reference 5), and following the method outlined by Doctor Schweitzer the boundaries of combustion were laid out for the E_6 nozzle as shown in Figure 5. If the volume within this boundary is assumed to be a minimum space requirement for combustion, it may be seen that the boundaries overlap and that the sprays probably interfere with each other during combustion.

When the series of nozzles for the investigation of the effect of angular spacing was designed, it was again necessary to deviate from the proportional-area principle for the volume of air to be served by each orifice changed with the angle. However, as the orifice sizes were maintained the same for all angles, the departure from the proportional-area principle averaged about 1 per cent, and this was neglected as it was less than the error in the determination of performance values. Accordingly, the different nozzles were made with corresponding orifices of the same size.

The nozzles in this series are designated by the letter F with a number denoting the angle in degrees between the axes of the orifices. Thus, the E_6 and the F_{20} are identical nozzles.

The performance tests of these nozzles showed very little difference between them, so far as the curves in Figure 6 are concerned, but observation of the exhaust gases and the sensitiveness to controls led to the decision to standardize on an angle of 25° for future work with this cylinder head.

As a further check, to indicate whether the 29° spacing was beyond the useful limit, two 0.005-inch orifices were added to the F_{29} nozzle in the center to see if any unused air remained between the 2 main sprays. The resulting increase in performance, as shown in the curves of Figure 7, indicates that small filler sprays are effective when the angle between the sprays on either side is too great.

It is believed that a nozzle which would be designated F_{25} would give sufficiently good performance and that any increase which could be secured by further refinements in nozzle design would hardly be commensurate with the complication involved in the construction of such a nozzle. However, the performance data do not show that angular spacing is at all critical within the range covered in these tests. The reason for this lack of criticalness is suggested by the small percentages of fuel in the outer part of the spray as shown by the dispersion data in Reference 5.

These tests do not complete the work to be done in investigating the quiescent combustion chamber. In all tests thus far the total discharge area has been disregarded and considered as a function of the injection system rather than of the combustion chamber. As it seems logical to investigate variation in total discharge area along with variation in total air available, additional data concerning this variation will be obtained in forthcoming supercharging tests.

Conclusions

Although the tests reported herein and in Reference 1 were conducted on a particular cylinder head, they indicate that there are definite basic requirements which must be satisfied in the design of multiple-orifice fuel-injection valve nozzles for use in combustion with a quiescent combustion chamber to insure the necessary mixture of fuel and air.

The fuel-injection system should be so designed that the same pressure is effective in causing the discharge through each orifice. The orifices themselves should be of the same geometric shape so that they all have the same coefficient of discharge. If these two conditions are satisfied, the nozzle will be able to meter the fuel to the combustion air by having the area of the individual orifices proportional to the volume of air served by each orifice.

These engine performance tests show that, in a multiple-orifice fuel-injection valve nozzle for a quiescent combustion chamber, there is no sharply defined optimum value for the number or direction of the orifices.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., May 15, 1931.

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3. Hicks, Chester W. and Moore, Charles S. : The Determination of Several Spray Characteristics of a High-Speed Oil Engine Injection System with an Oscilloscope. N.A.C.A. Technical Note No. 298, Sept., 1928.

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5. Schweitzer, P. H. : Factors in Nozzle Design in the Light of Recent Oil Spray Research. No. OGP-52-15. page 121, Transactions of A.S.M.E., 1930.

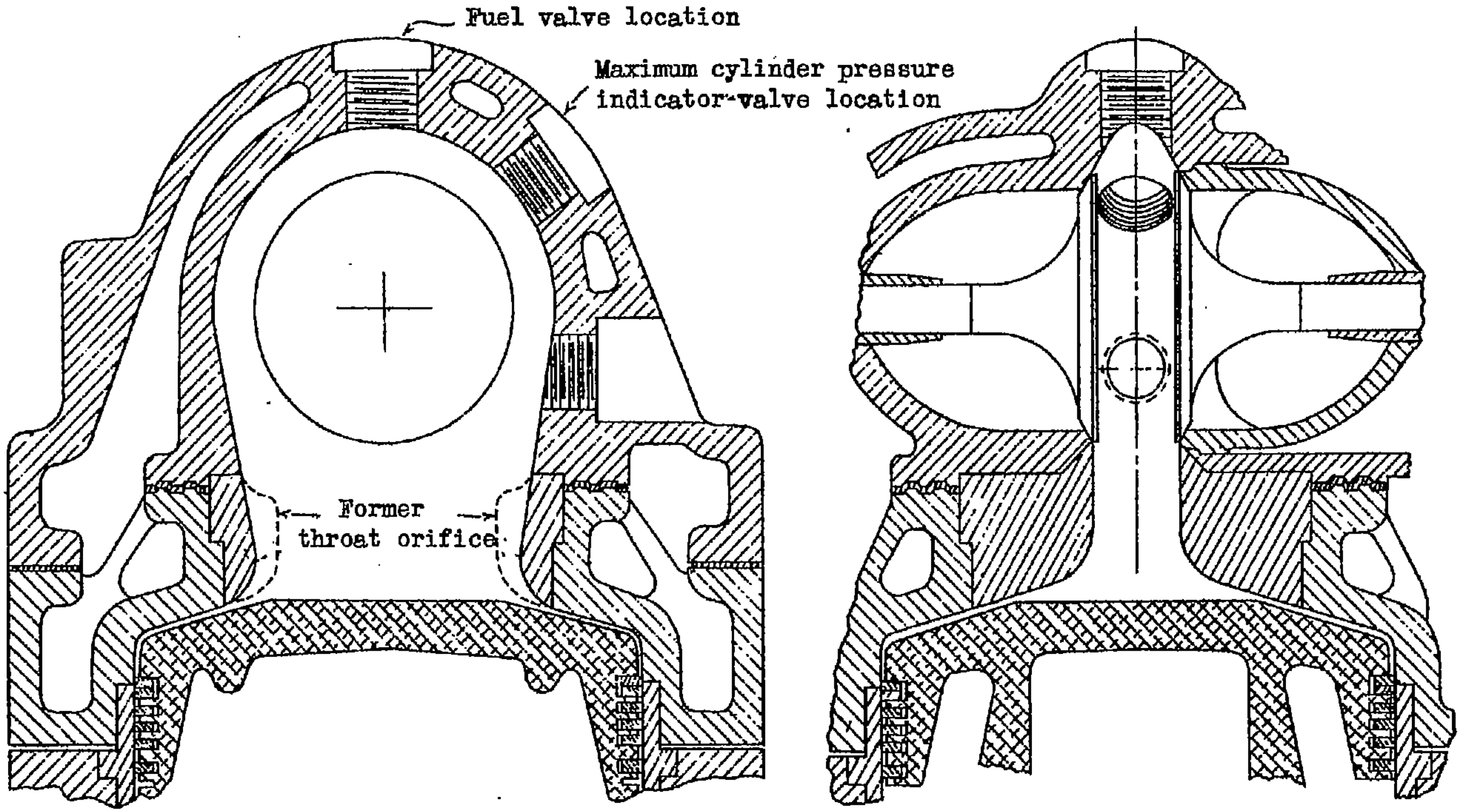
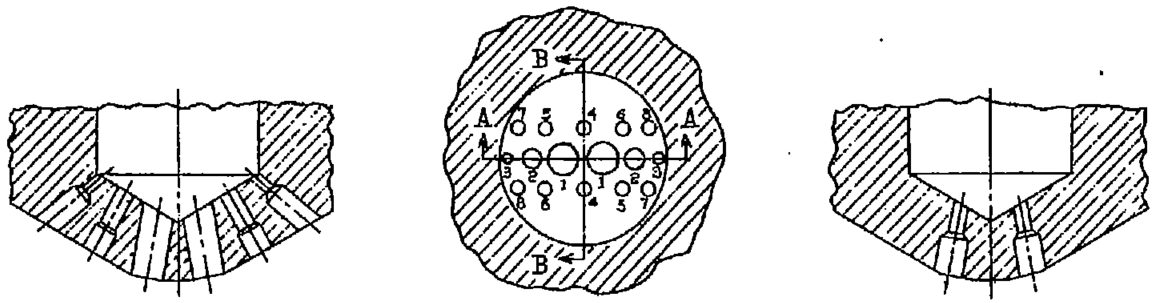


Fig. 1 Combustion chamber.

Fig. 2



Section A-A

Plan view of nozzle

Section B-B

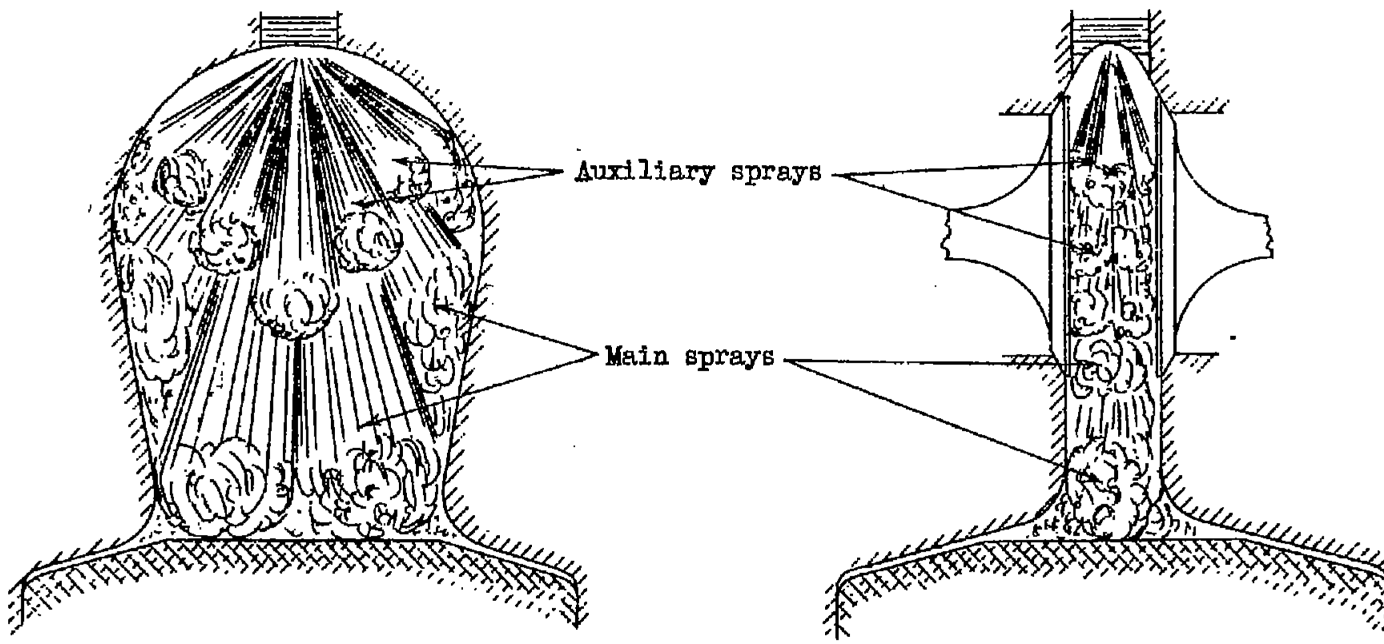


Fig. 2 Projected spray distribution using nozzle E-16

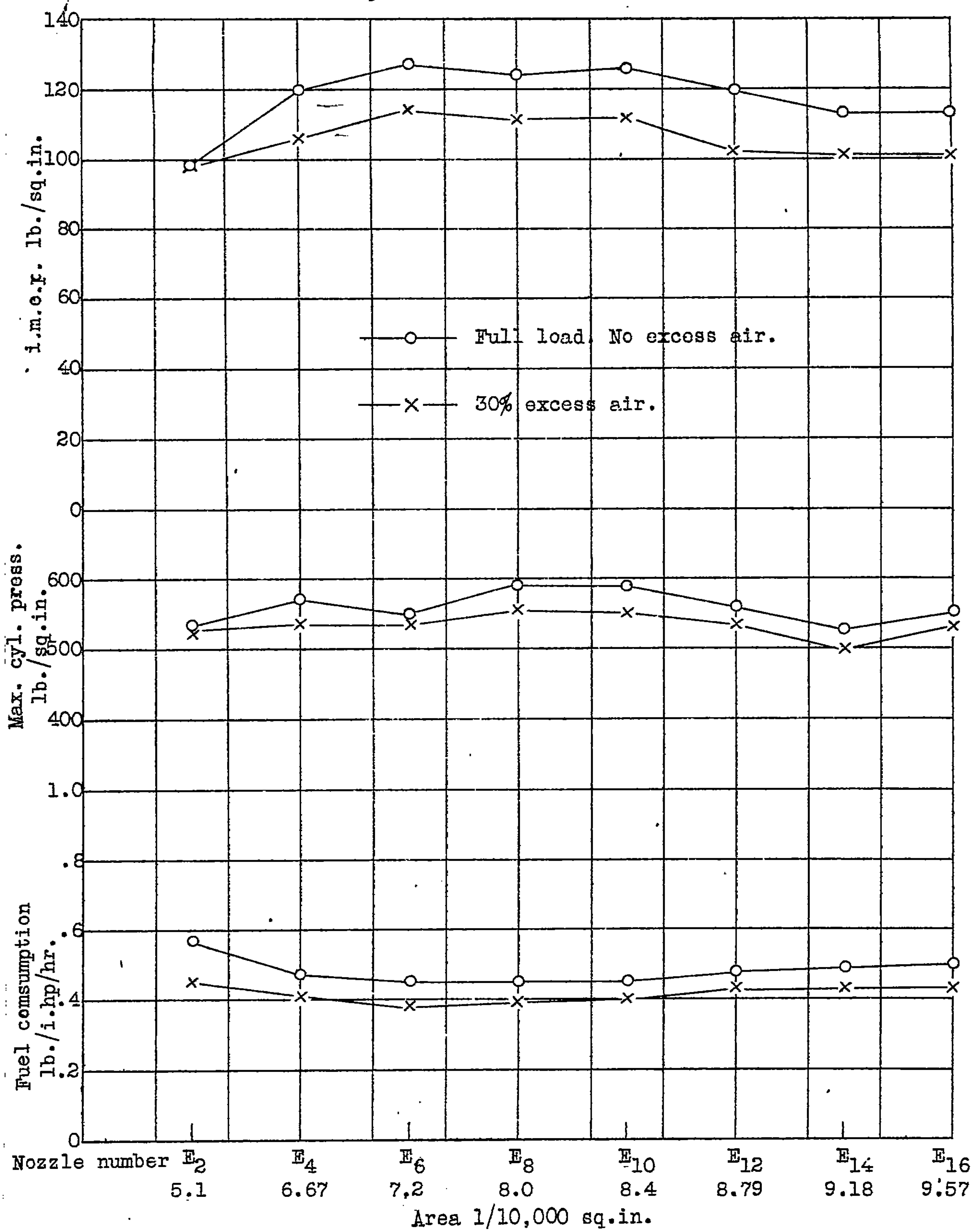


Fig. 3 Comparison of engine performance using injection nozzles E_2 - E_{16}

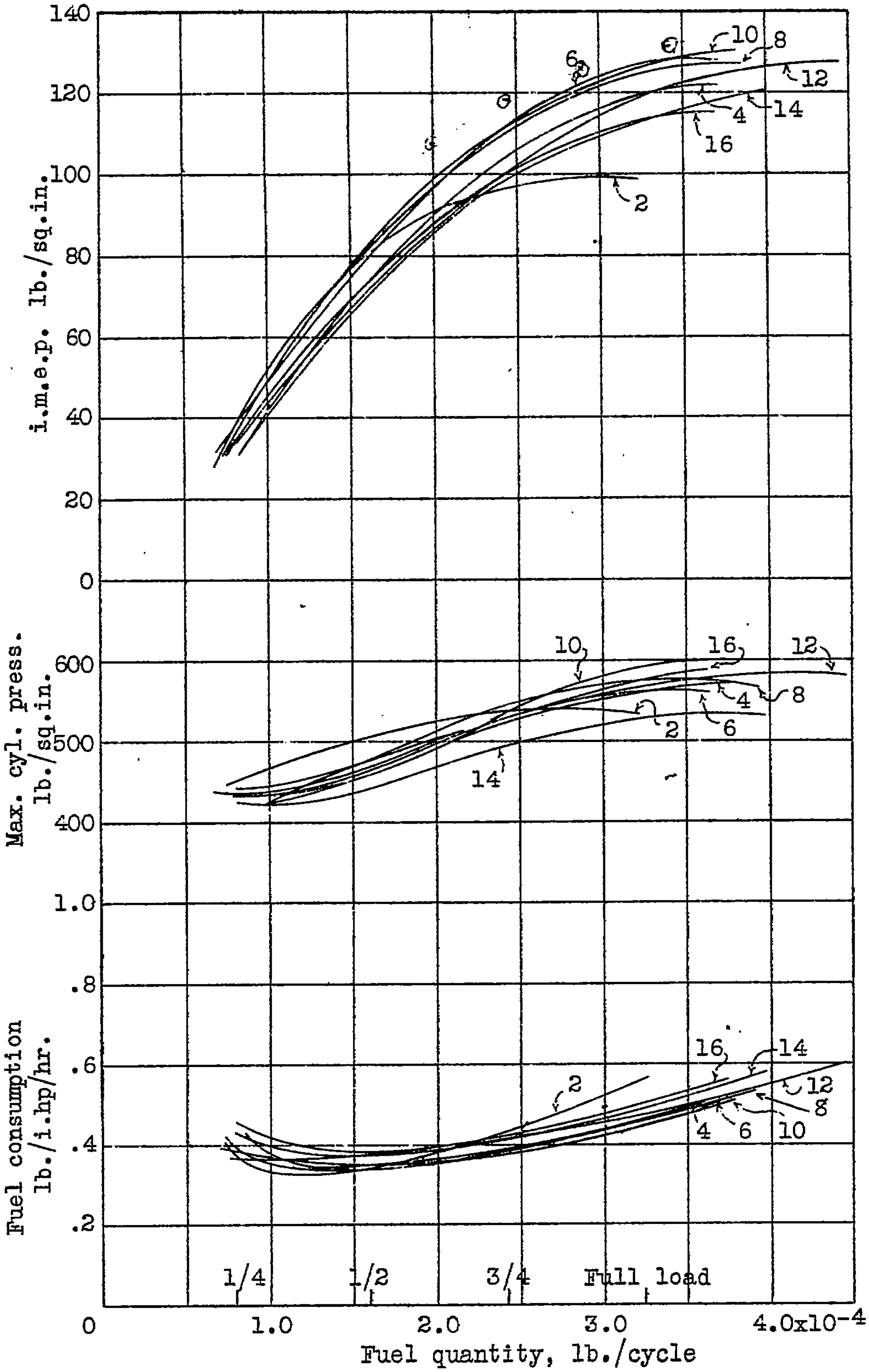


Fig. 4 Comparison of engine performance using injection nozzles $E_2 - E_{16}$

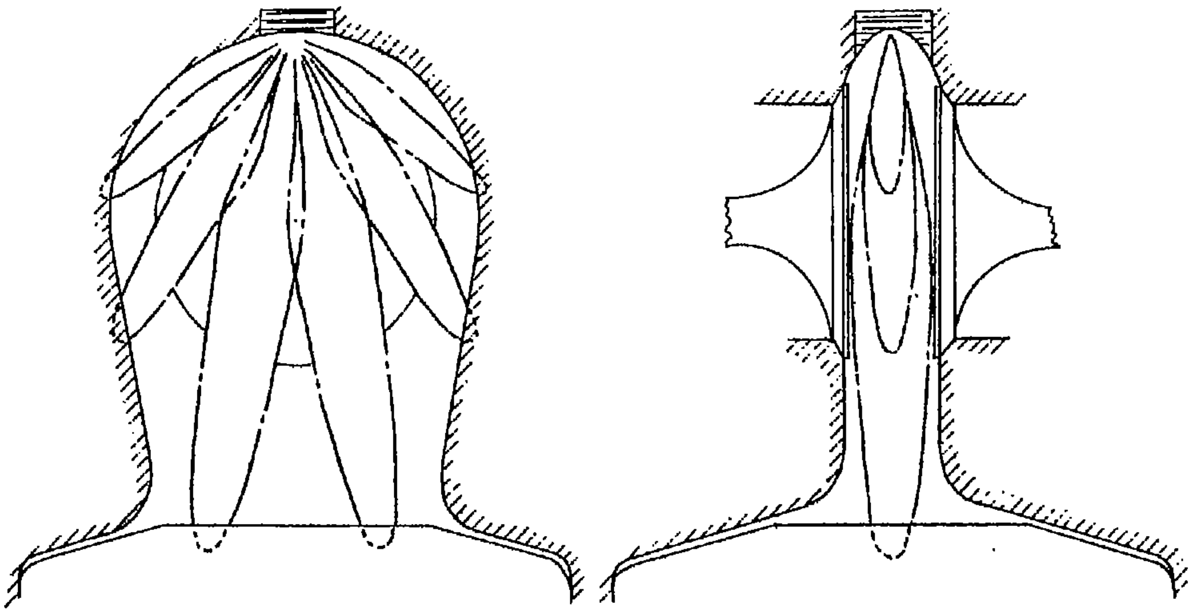


Fig. 5 Boundaries of combustion using nozzle E_6

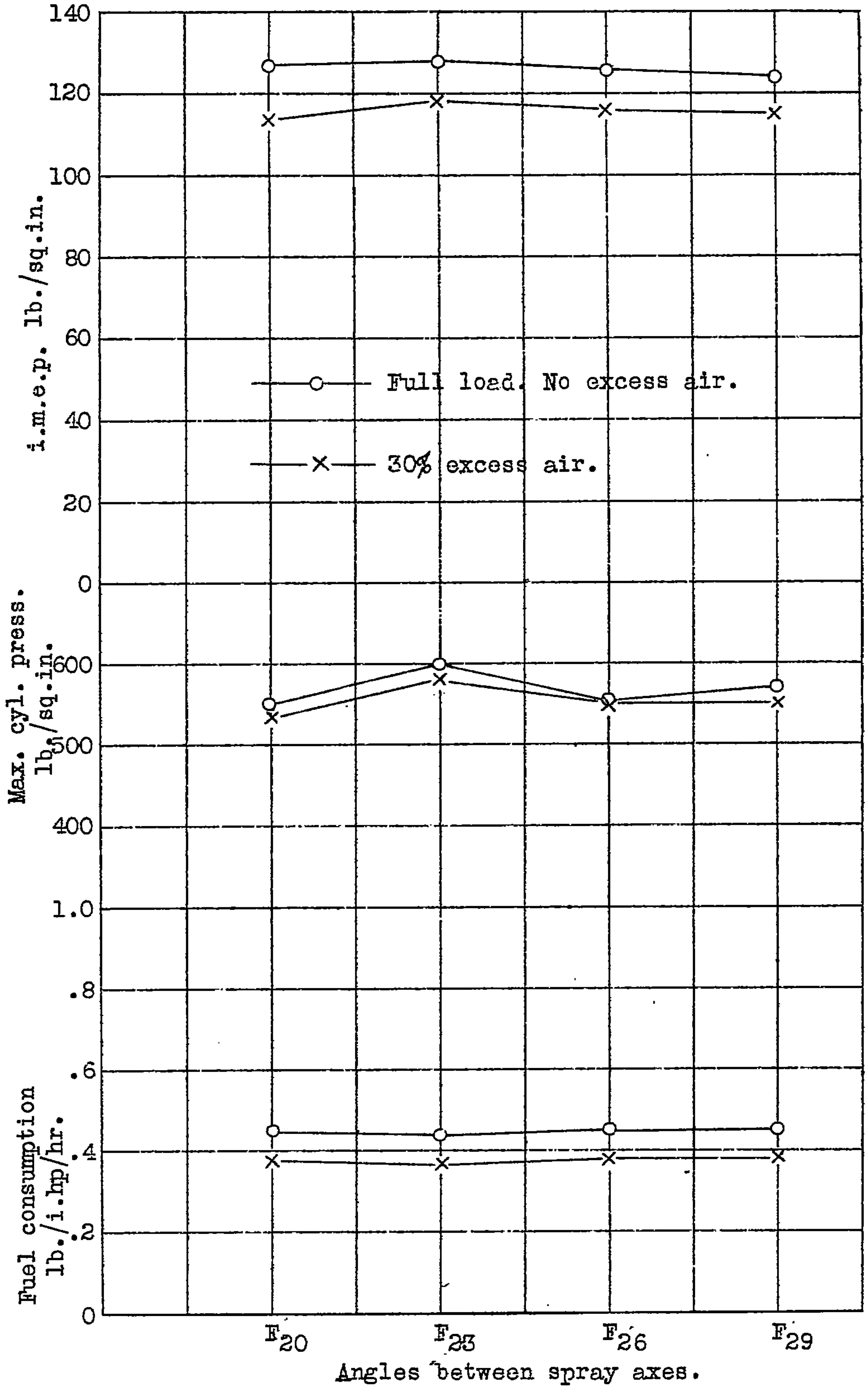


Fig. 6 Effect of spray spacing on engine performance.

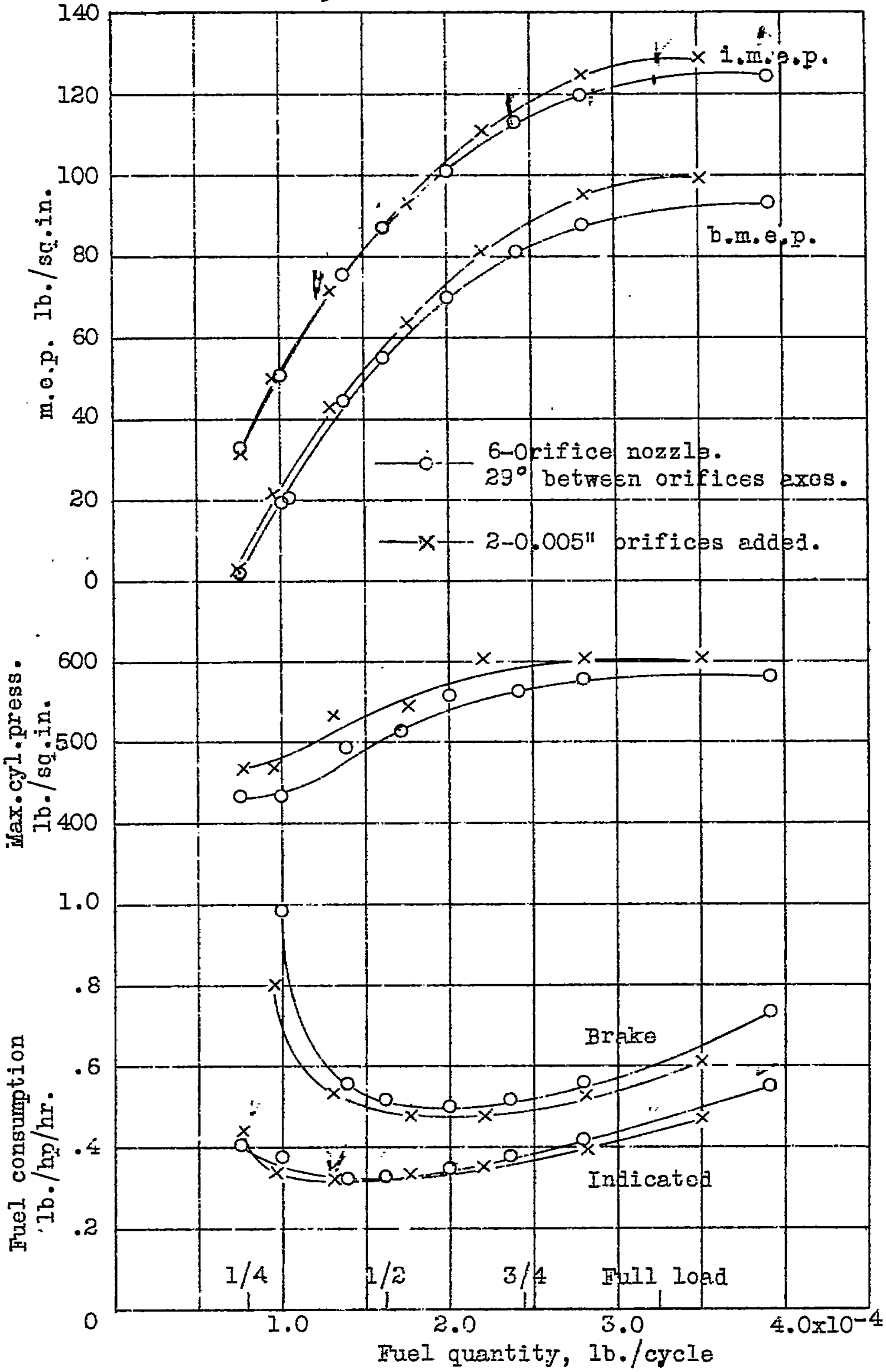


Fig. 7 Effect of distribution on engine performance.